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Sports Performance Benefits from Taking Natural Astaxanthin

*** Characterized by Visual Acuity and Muscular Fatigue**

Improvement in Humans

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Abstract:

The effect of Astaxanthin on visual acuity and muscle fatigue were studied. Astaxanthin (3,3'-Dihydroxy- β -carotene-4,4'-dione) is a red pigment found in salmon and krill and has strong antioxidant properties. In the two supplementation studies, astaxanthin extracted from algae (*Haematococcus pluvialis*) was used. Four visual acuity parameters were examined in experiment A in 18 healthy adult male volunteers that were equally divided into two groups (treatment and control). The measured parameters were deep vision, critical flicker fusion, static and kinetic visual acuity before and after supplementation. A second investigation (experiment B) involved 16 adult male volunteers to establish the effect of astaxanthin supplementation on the build up of lactic acid before and after running 1,200 meters, the treated groups ingested an astaxanthin capsule per day for 4 weeks (6mg astaxanthin per day) and the control groups received a placebo capsule.

Results : In experiment A, the deep vision and the critical flicker fusion of the treated groups were significantly improved compared to the control group. No effects of treated group were observed on static and kinetic visual acuity. In experiment B, serum lactic acid concentration at 2 minutes after activity (1,200 m running) of the treated group was significantly lower than that of the control one. No other effects related to supplementation of astaxanthin on serum biological and hematological examinations were observed.

Based on these preliminary findings, it was suggested that supplementation of astaxanthin is effective for the improvement of visual acuity and muscular fatigue that may lead to sports performance benefits.

Key words : Astaxanthin; Visual acuity; Muscular fatigue

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Introduction

Astaxanthin (Fig.1) is a kind of carotenoids including β -carotene (Fig.2) etc. and a natural red color widely and naturally distributed in oceanic lives, such *Crustacea* as shrimps, crabs etc. and such fishes as salmon, sea breams etc. which have been well-eaten.

Recently, strong anti-oxidative action ^{1) 2)} of astaxanthin was reported, exhibiting 100~1,000 times stronger than Vitamin E (α -tocopherol), approximately 40 times stronger than β -carotene in its anti-oxidative activity and astaxanthin has become one of major materials for health foods expecting prevention of Lifestyle-Related Diseases, hoped eagerly by the industries, although, in the past, it was only used as a color (a color food additive ³⁾ or a dye-up agent for cultured fishes).

Furthermore, its other various specific actions have been reported, such as anti-inflammatory action ⁴⁾, anti-arteriosclerotic action ^{5) 6)}, inhibiting action against progression of diabetes ⁷⁾ and its complications such as cataract ⁸⁾ and nephropathy ⁷⁾, and retinal protective action against light-induced injury ⁹⁾, daily rhythm regulating action ¹⁰⁾, brain protective action against ischemic damages ¹¹⁾, immunomodulating action ¹²⁾, anti-stress action ¹³⁾, improving action of duration of muscular function ¹⁴⁾, improving action of semen quality ¹⁵⁾, improving action against hepatic disorders ¹⁶⁾, inhibiting action against carcinogenesis (oral cavity ¹⁷⁾, colon ¹⁸⁾, urinary bladder ¹⁹⁾, liver ²⁰⁾, prostate ²¹⁾), and dermatological actions in oral or topical use (inhibition of hyperpigmentation ²²⁾, inhibitions of light-induced skin aging and melanin-generation ²³⁾, cosmetic benefit < wrinkle reduction > effect ^{24) 25)}).

On the other hand, there has been almost no data reported on evaluation of astaxanthin effect in sports field.

It is said that "the eye" has a very important role in athletic performance, because such expression has widely and frequently been taken in sports field as "a player who has high visual acuity in looking around" or "can see a ball very well" etc. "Sports vision" is a general term for visual acuity in sports field, and it has been positioned as the third Sports Science, following to "Physical Science" and "Mental Science" and regarded as a very important science ²⁶⁾. Recently, a correlation between high visual acuity including kinetic visual acuity and high athletic performance of the top-ranking athletes such as professional base-ball players, professional golfers etc. is now being elucidated ^{26)~28)}.

In hard physical exercise, anaerobic metabolism may function in the body and muscular fatigue may be induced due to formation of lactic acid (lactate)

in the muscle ²⁹⁾. Then, it is suggested that a performance ability may decrease much, if the succeeding exercise would be done within such condition as just keeping increased level of lactate rather than the level at rest condition ^{30) 31)}.

As for sports activities, especially, distance runners playing for track and field races can improve their performance ability by daily continuation of hard and high quality training. Therefore, it will be a very important theme how quickly they can recover themselves from their fatigue produced by daily training.

In this study, we purposed to elucidate effects of astaxanthin on improvement of visual acuity and muscular fatigue after exercise.

I. Method

A study protocol was prepared and the study was performed in accordance with this protocol. Subjects consisted of volunteers who were enrolled voluntarily and received, at first, explanation of study details and then signed on the informed consent.

1. Material

Astaxanthin capsules manufactured by Fuji Chemical Industry Co., Ltd.

(6 mg of astaxanthin per capsule) were used for the test group and placebo capsules (0 mg of astaxanthin per capsule) for the control group respectively. Furthermore, the both capsule films were stained in order to make them undistinguishable. The astaxanthin was extracted and concentrated from algae of *Haematococcus pluvialis*.

The study was performed with double-blind manner; for administration of preparations, a team manager kept them in his charge and at each time for administration, handed to the subject the preparations which were allocated in accordance with an allocation-table previously prepared by a controller and confirmed compliance of their administration. The preparations were administered with water, before starting exercise at the day for training or before lunch at the day for no training.

2. Medical examination including blood biochemical and hematological tests

Blood biochemical tests (Total protein, A/G ratio, BUN, CRE, UA, T-Chol, HDL-C, TG, T-Bill, GOT, GPT, ALP, LDH, γ -GTP, Blood glucose, Na, Cl, K, Ca and Mg) and hematological tests (WBC, RBC, Hgb, Hct, MCV, MCH and Platelet counts) were performed at rest condition (before exercise) in order

to check health condition of the subjects, before administration, after completion of administration for 4 weeks and after the period of no supplementation.

Every blood sampling was initiated from 15:30. In experiment B, the blood sampling was also performed after exercise in order to compare the outcomes obtained before and after exercise. Practice of blood sampling and measurements was committed to Health Science Institute Co.,(Kobe-cho, 106, Hodogaya, Yokohama, Kanagawa).

3. Test method

1) Experiment A: Effect of astaxanthin on visual acuity

(1) Subjects

18 members from handball team of J-University which belongs to the first league of Kanto College Handball Association were enrolled as subjects. The subjects were randomly divided into two groups; one group for astaxanthin administration (hereinafter referred to as Test group; 9 subjects) and another group for placebo administration (Control group; 9 subjects) respectively. Table 1 shows subject profiles.

(2) Test duration and place

The test duration was 3 months, from November 2001 to January 2002. Astaxanthin and placebo were administered for 4 weeks.

Blood examinations and functional measurement were conducted in an experiment-practice room of J-University. The content of exercise for the test was the same in its hardness as the content which was practiced in the training specialized by J-handball team (Table 2). Such exercises were practiced in Cosmo-Hall of J-University with the same content and at the same period of time for both, before administration period and after completion of administration period. Fig.3 shows a protocol of experiment A.

(3) Items for functional measurements

Measurement items in this trial included static visual acuity, kinetic visual acuity and depth perception, regarded as absolutely important by Japanese Sports Vision Association for visual acuity in sports ^{32) 33)}. Critical flicker fusion test was also included in order to evaluate improvement of asthenopia.

Static visual acuity (SVA) : Kinetic visual acuity meter (Kowa Co., Kinetic Visual Acuity Meter AS-4C) was used with static visual acuity measuring mode.

Kinetic visual acuity (KVA) : Kinetic visual acuity meter (Kowa Co.,

Kinetic Visual Acuity Meter AS-4) was used. Kinetic visual acuity was measured in the following manner ; set a Landolt ring in such manner that it moves in close to 2 meter just front of eyes from 50 meter-distance at a speed of 30 km/hour and measure the distance met to where a subject can see clearly the directions of opened space (4 directions: top, bottom, left and right) of moving Landolt ring. 5 Measurements of KVA were performed on a subject's left, right and both eyes respectively and a geometrical mean value of 3 measurements was calculated after deleting both maximum and minimum values ³⁴⁾.

Depth perception (DP) : Depth perception was measured using an apparatus (Kowa, AS-7JS1) in the following manner ; fix a subject's head on a chin rest which is positioned 2.5 meters far from the apparatus which has 2 rods fixed parallelly and another one rod moving for directions in front and in rear at a speed of 50 mm/sec between the two fixed rods ; a subject flips a switch when he judges that these 3 rods come into line horizontally ; measure ,at this moment, the distance from the both fixed rods to the moving rod.

3 Measurements of such distance (error) were performed and a mean value of 3 measurements was calculated ³³⁾.

Critical flicker fusion : Critical flicker fusion meter (Yagami, FV-20) was used for measurement in the following manner of an ascending method ; a subject puts his eyes on the eye-placing point of the apparatus and looks flickering light in center of his visual field and then pushes a button when he becomes not to feel such flickering ; at this moment, read the value shown in the indicator.

3 Measurements were performed respectively and their mean value provides a flicker value.

(4) Statistical analysis

Comparison of values obtained in measurement of visual acuity : The values of each group were compared between the values before and after period of administration as well as the values before and after exercise by paired *t*-test. Comparison between Test and Control groups was performed by unpaired *t*-test. The values of depth perception, however, were analyzed by Welch's method because they did not show homoscedasticity. Level of significance: $p < 0.05$.

2) Experiment B: Effect of astaxanthin on improvement of muscular fatigue

(1) Subjects

16 Subjects were enrolled voluntarily from distance runners belong to Field and Track Athletic Team of J-University. The subjects were divided randomly into 2 groups, one group for astaxanthin administration (hereinafter referred to as Test group: 8 subjects) and another group for placebo administration (Control group: 8 subjects) respectively. Table 1 shows subject profile.

(2) Test period and place

The test duration was 3 months, from November 2001 to January 2002. Astaxanthin and placebo were administered for 4 weeks.

Blood examinations were conducted in an experimental-practice room in J-University. Fig.4 shows a protocol of experiment B.

(3) Items of measurement

Measurements include the following items.

Creatinekinase (CK): Serum CK value, one of indicators showing a degree of muscular fatigue, was obtained by blood biochemical test performed before and after exercise.

Serum lactate level: Before and after administration period, all subjects were allowed to run for 1,200 meters with the same loading strength as that of their own maximum record achieved in 5,000 meter-running. Blood sampling from finger top was performed before exercise, 2, 4, 8 and 10 minutes after exercise. The serum lactate level was analyzed using lactic acid analyzer, Lactate-Pro (Arclay Marketing Co.). All measurements were performed at the athletic grounds of J-University.

Heart rate: Heart rate was measured at rest condition before and after administration period and at 1 minute after the loading exercise. Measurement of heart rate was conducted by the subject himself digitally touching on the radial artery.

(4) Statistical analysis

CK values, serum lactate levels and heart rates between the values obtained before and after the exercise done before and after administration period were compared using paired *t*-test. Furthermore, comparison between Test and Control groups was performed by unpaired *t*-test. Level of significance: $p < 0.05$.

II. Results and Discussion

1. Experiment A

1) Blood examinations

Tables 3 (1) and (2) show the values obtained from blood biochemical and hematological tests which were performed at rest condition before and after administration period and 5 weeks after completion of administration, and their mean values and standard deviations. No effect of astaxanthin supplementation on the above values was observed.

2) Static visual acuity

No significance was observed in comparison between values obtained before and after administration period in both Test group and Control group. Furthermore, no significance was also observed between Test and Control groups (Table 4). It is suggested that astaxanthin supplementation for 4 weeks may not effect on static visual acuity.

3) Kinetic visual acuity

No significance was observed in comparison between the values obtained before and after administration period in both Test group and Control group. Furthermore, no significance was also observed between Test and Control groups (Table 4). Kinetic visual acuity includes two kinds; one is a visual acuity to look a target moving in transverse direction (DVA: hereinafter referred to as "DVA") and another one is to look a target coming in close to (KVA: hereinafter referred to as "kinetic visual acuity" limited in this paper). The latter acuity has generally been regarded as KVA in Japan. It is said that KVA is an important acuity in sports, for instance, necessary in a case to look clearly a ball coming in close to ³³⁾.

In this experiment, astaxanthin supplementation alone did not improve KVA. The fact that no improvement of KVA was observed in this experiment could be resulted from the outcome that a correlation between KVA and SVA was confirmed in the preliminary experiment. In order to improve KVA, however, it may be necessary to discuss not only to improve SVA but also to practice sports vision training to improve KVA as well as simultaneous supplementation of astaxanthin.

4) Ratio of kinetic visual acuity to static visual acuity

Neither significance in comparison between values obtained before and after administration period in both Test and Control groups nor significance between Test and Control groups was observed (Table 4). In a ratio of KVA to SVA ($KVA/SVA \times 100\%$), general people show it at 60%, sports players (ball game players) at 70% or more, especially professional baseball players at 80~90%. It is said that the higher ratio meets to the higher performance.

From the results of this experiment, the ratio obtained in both Test and Control groups showed low, approximately at 50%. It was confirmed that all subjects of the both groups had relatively low KVA, even though they are handball players.

5) Depth perception

In Control group, the mean values obtained from outcomes after exercise-before administration period and before exercise-after administration period showed significantly smaller than the mean value before exercise-before administration period. In Control group, however, the mean values obtained from outcomes after exercise-before administration period and before exercise-after administration period showed significantly large. On the other hand, in Test group, no significant difference was observed between the values obtained before and after administration period. In comparison between Test and Control groups, the value, 7.86mm obtained after exercise-after administration period in Test group showed significantly smaller than the value, 17.60mm obtained after exercise-after administration period in Control group (Fig.5).

Depth perception (DP) provides a degree of cubic visual acuity with both eyes ²⁷⁾ that is an indispensable acuity to recognize a located point and distance in front and in rear of a target ³³⁾. Especially, DP may contribute to such performances in sports as; when a baseball player is going to catch a ball; when a tennis player is going to smash; and in other ball games, when a player has to have the sense of distance to a goal and to grasp the positions of a moving ball and players ³⁵⁾.

In this experiment, the mean value, 30.01mm and SD, 25.02mm obtained before exercise-before administration period in Control group showed very large compared to other outcomes. It seemed to give a reason why such significant difference was observed. Furthermore, the value, 7.96mm obtained after exercise-before administration showed significantly smaller than the value, 17.60mm obtained before exercise-after administration period in Control group. This fact may suggest that the ability of depth perception was deteriorated at the time before and after administration period in Control group. On the other hand, in comparison of outcomes obtained after exercise-after administration period between Test and Control groups, Test group showed an outcome of higher depth perception ability compared to Control group. This fact suggested that a certain correlation might exist between astaxanthin and depth perception. Then, such visual acuity shall further be discussed.

6) Critical flicker fusion (CFF)

In Test group, the mean values of CFF obtained after exercise-before and after administration period moved significantly from 36.84 to 38.70 and the mean values of CFF obtained after exercise-before administration period and before exercise-after administration period moved also significantly from 36.84 to 37.50. In Control group, however, the mean values of CFF did not show any significance between the outcomes before and after administration period. Furthermore, no significance was also observed between Test and Control groups (Fig.6).

CFF level provides a criteria to evaluate the degree of visual fatigue based on such property that fatigue allows visual sensation to blunt and high CFF level makes the visual cortex or retinal nerve sensitive but the lower level provides the higher degree of fatigue in visual sensation system ³⁶⁾.

The results of this experiment elucidated two special features. One is that CFF level observed after exercise was higher than that of before exercise in each group respectively. The cause of this fact may depend on improving blood circulation by exercise that makes visual sensation much sensitive. Another one is that CFF level obtained after administration period increased significantly higher than that of before administration period. This fact suggests that astaxanthin supplementation may accelerate blood circulation in fatigued visual sensation (sharpening of visual sensation).

2. Experiment B

1) Blood examinations

Blood examinations were performed before and after administration period and 3 weeks after completion of administration at rest condition respectively. Table 5 (1) and (2) show values obtained in blood biochemical tests and hematological tests, the mean values and standard deviations. Any effect of astaxanthin supplementation on the above values was not observed.

2) CK level

Any significant change in CK level was not observed among the values obtained before and after exercise-before and after administration period in both Test and Control groups. In Test group, however, the mean value obtained after exercise-after administration period showed lower than that obtained after exercise-before administration. This fact may suggest that the muscular fatigue was reduced (Fig.7).

3) Serum lactate level

In comparison of serum lactate levels obtained after 1,200m running

exercise between before and after administration period in Test group, no significance was observed in the values obtained after administration period at rest, 4, 8 and 10 minutes after the exercise compared to those values obtained before administration period. The values obtained 2 minutes after the exercise, however, showed significant difference ($p < 0.05$) (Fig.8).

As the serum lactate levels obtained just (2 minutes) after the exercise with the same loading level in its hardness showed a significant difference, it may suggest that aerobic metabolism in muscle cells was improved. Furthermore, the values obtained 4, 8 and 10 minutes after the exercise-after administration period showed a decreasing tendency compared to those obtained before administration in spite of showing no significant difference. This fact suggests that astaxanthin supplementation may effect to accelerate deletion of lactic acid in muscle cells. On the other hand, in Control group, no significant difference was observed in comparison of serum lactate levels obtained after 1,200m running exercise between the values before and after administration period (Fig.8).

4) Heart rate

In comparison of the heart rates counted at 1 minute after 1,200m running exercise between the rates obtained before and after administration period, no difference was observed in both Test and Control groups (Table 6). It was suggested that the loading strength of exercise performed before and after administration period seemed the same in their hardness in the both groups.

III. Summary and Conclusion

Effects of astaxanthin supplementation on visual acuity and muscular fatigue studied in this trial are summarized and concluded as follows:

- 1) No effect of astaxanthin supplementation on the subjects' health condition was observed.
- 2) No change in the values obtained for static visual acuity and kinetic visual acuity measured before and after supplementation of astaxanthin was observed.
- 3) In comparison of depth perception values between Test and Control groups, the value obtained after astaxanthin supplementation (Test group) seemed to exceed than that of Control group.
- 4) In comparison of critical flicker fusion between Test and Control groups, the visual sensation was observed significantly sharpened in Test

group.

- 5) No difference of CK values between the values obtained before and after astaxanthin supplementation was observed.
- 6) In comparison of serum lactate levels measured at 2 minutes after exercise, the level measured after astaxanthin supplementation decreased significantly compared to the level before astaxanthin supplementation.
- 7) No difference of heart rates measured after exercise was observed between the rates, before and after astaxanthin supplementation.

From the above results, it suggests that astaxanthin supplementation is effective for improvement against bluntness of visual nerve acuity and for inhibition of lactic acid generation induced by the continuous muscular contracting activities (Improvement of activity in endurable hard exercise).

Reference

- 1) Miki, W.: Biological functions and activities of animal carotenoids. *Pure & Appl. Chem.*, **63** : 141-146, 1989.
- 2) Shimizu, N., Goto, M., Miki, W.: Carotenoids as singlet oxygen quenchers in marine organisms. *Fisheries Science*, **62** : 134-137, 1996.
- 3) *Annotation Book for Existing Additives Name List*: The List Annotation, Existing Additives Name Number (403), Japan Food Additive Association, p488, 1999.
- 4) Kurashige, M., Okazoe, Y., Okimasu, A. et al.: Cell membrane injury by free radicals and its protection by astaxanthin. *Cytoprotection & Biology*, **7**: 383-391, 1989.
- 5) Iwamoto, T., Hosoda, K., Hirano, R., et al.: Inhibition of low-density lipo-protein oxidation by astaxanthin. *J. Atheroscler. Thromb.*, **7**: 216-222, 2000.
- 6) Iino, T., Ono, K. and Kiso, Y.: Interaction of astaxanthin and lycopene indicating by LDL-oxidized ability. *The 55th Meeting of Japanese Nutrition and Food Society*, Kyoto, 2G-07a, 2001.
- 7) Uchiyama, K., Naito, Y., Hasegawa, G., et al.: Astaxanthin protects pancreatic -cell in diabetic db/db mice. *Carotenoid Science*, **5**: 30-31, 2002.
- 8) Kenmotsu, N., Jimaima, J., Arai, H. et al.: Effects of astaxanthin on the diabetic cataract. *The 51st Meeting of Japanese Nutrition and Food Society*, Tokyo, pp170, 1997.
- 9) Tso, O. M., Lam, Tim-Tak.: Method of retarding and ameliorating central nervous system and eye damage. *USPAT*, 5527533, 1996.

5: 21-24, 2002.

- 24) Seki, T., Sueki, H., Kawano, H., et al: Effect of astaxanthin from *Haemato-*
coccus pluvialis on human skin – Patch test, repeated application test
on human skin and effect on wrinkle reduction – *Fragrance Journal*, 29:
98-103, 2001.
- 25) Yamashita, E.: Cosmetic benefit of the supplemental health food
combined
with astaxanthin and tocotrienol on human skin. *Food Style* 21,
6: 112-117,
2002.
- 26) Mashita, I., Ishigaki, T., Edagawa, H., et al: Utilization of sports vision
(Feed-back to practice). *Clin.Sports Med.*, 14(8): 921-924, 1997.
- 27) Ishigaki, T.: Measurement and evaluation of sports vision. *Clin.Sports*
Med., 12(10): 1105-1112, 1995.
- 28) Mashita, I.: Sports vision for each athletic item. *Clin.Sports.Med.*, 12(10):
1113-1119, 1995.
- 29) Hermansen, L. : Muscular fatigue during maximal exercise of short
duration. *Med.Sci.Sport.*, 13: 45-52, 1981.
- 30) Hogan, M.C., Welch, H.G.: Effect of lactate levels on bicycle ergometer
performance. *Am.J.Physiol.Scci.*, 57: 507-513, 1984.
- 31) Klausen, H., Gknuttgen, H., Forster, H.V.: Effect of pre-existing high blood
lactate concentration on maximal exercise performance. *Scan.J.Clin.*
Lab.
Invest., 30: 415-419, 1972.
- 32) Mashita, I.: Kinetic visual acuity. *Physical Strength Science*, 46: 321-326,
1997
- 33) Sports Vision Research Association: Sports vision-Visionology for sports.
55-76, 1997.
- 34) Stine, C.: Vision and Sports-A review of literature. *J.Am.Optomeric*
Assoc. 53(8): 627-633, 1982.
- 35) Arthur, S., Steven, S. : "The eye of top-players". transl. and edit. by
Shiroyama, S., Maeda, K., Taishukan Book, 35-37, 1991.
- 36) Ishi, N. : Terminological Dictionary for Athletic Training. 489, Health
Department, Morinaga Seika Co., Ltd., 2001.

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Effects of astaxanthin on accommodation, critical flicker fusion, and pattern visual evoked potential in visual display terminal workers

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